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Availability, affordability, and consumption of fruits and vegetables in 18 countries across income levels: findings from the Prospective Urban Rural Epidemiology (PURE) study

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Summary

Background Several international guidelines recommend the consumption of two servings of fruits and three servings of vegetables per day, but their intake is thought to be low worldwide. We aimed to determine the extent to which such low intake is related to availability and affordability.

Methods We assessed fruit and vegetable consumption using data from country-specific, validated semi-quantitative food frequency questionnaires in the Prospective Urban Rural Epidemiology (PURE) study, which enrolled participants from communities in 18 countries between Jan 1, 2003, and Dec 31, 2013. We documented household income data from participants in these communities; we also recorded the diversity and non-sale prices of fruits and vegetables from grocery stores and market places between Jan 1, 2009, and Dec 31, 2013. We determined the cost of fruits and vegetables relative to income per household member. Linear random effects models, adjusting for the clustering of households within communities, were used to assess mean fruit and vegetable intake by their relative cost.

Findings Of 143 305 participants who reported plausible energy intake in the food frequency questionnaire, mean fruit and vegetable intake was 3·76 servings (95% CI 3·66–3·86) per day. Mean daily consumption was 2·14 servings (1·93–2·36) in low-income countries (LICs), 3·17 servings (2·99–3·35) in lower-middle-income countries (LMICs), 4·31 servings (4·09–4·53) in upper-middle-income countries (UMICs), and 5·42 servings (5·13–5·71) in high-income countries (HICs). In 130 402 participants who had household income data available, the cost of two servings of fruits and three servings of vegetables per day per individual accounted for 51·97% (95% CI 46·06–57·88) of household income in LICs, 18·10% (14·53–21·68) in LMICs, 15·87% (11·51–20·23) in UMICs, and 1·85% (–3·90 to 7·59) in HICs (p_{trend}=0·0001). In all regions, a higher percentage of income to meet the guidelines was required in rural areas than in urban areas (p<0·0001 for each pairwise comparison). Fruit and vegetable consumption among individuals decreased as the relative cost increased (p_{trend}=0·00040).

Interpretation The consumption of fruit and vegetables is low worldwide, particularly in LICs, and this is associated with low affordability. Policies worldwide should enhance the availability and affordability of fruits and vegetables.

Funding Population Health Research Institute, the Canadian Institutes of Health Research, Heart and Stroke Foundation of Ontario, AstraZeneca (Canada), Sanofi-Aventis (France and Canada), Boehringer Ingelheim (Germany and Canada), Servier, GlaxoSmithKline, Novartis, King Pharma, and national or local organisations in participating countries.

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Introduction

Most nutritional guidelines recommend the consumption of at least two servings of fruits and three servings of vegetables per day.[1,2] However, a large proportion of individuals do not meet these targets.[3–5] An improved understanding of the factors that affect fruit and vegetable consumption is essential to improving the diet quality of populations.

Food cost has been shown to affect dietary intake in developed countries,[6,7] but similar data for low-income countries (LICs) and middle-income countries (MICs) are sparse. High food cost might particularly affect affordability among households spending a considerable proportion of their income on food.[8,9] Increases in the cost of food have been shown to result in food-based coping strategies such as reductions in the quantity, quality, and diversity of food selections, and consumption of increased quantities of cheap, energy-dense foods.[10–12]

Determining the affordability of essential foods such as fruits and vegetables in countries with different levels of economic development is important. In this study, we aimed to document the availability cost of fruits and vegetables in community grocery stores and market places, and the affordability of meeting dietary guidelines

Lancet Glob Health 2016; 4: e695–703

Published Online August 23, 2016 http://dx.doi.org/10.1016/S2214-109X(16)30186-3

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Research in context

Evidence before this study

We searched PubMed for articles published between Jan 1, 1960, and Jan 15, 2016, using the search term "fruit" OR "vegetable" OR "produce" OR "food" AND "cost" OR "afford*" OR "price" OR "purchasing" OR "availability" OR "diversity". We used search terms in English but did not apply any language restrictions. We screened papers by title and abstract to identify full-text reports that were relevant to the study aims. We also screened citation lists from these full-text reports to identify other relevant articles. Papers were considered relevant if they report assessment of the relation between fruit and vegetable intake and availability or affordability. The papers cited here were selected to be representative of the existing evidence base and are not an exhaustive list of relevant research. Existing evidence was limited to the affordability of healthy food items in high-income countries. The absolute cost of food items was reported in several papers. However, information on the relative cost and proportion of individuals unable to afford the food items was not described.

Added value of this study

To our knowledge, this study is the first to describe the availability and affordability of fruits and vegetables across economic regions globally and to relate affordability to consumption. Our results show that the consumption of fruits and vegetables is low worldwide, particularly in low-income countries because of low affordability.

Implications of all the available evidence

Most dietary guidelines recommend the consumption of two servings of fruits and three servings of vegetables per day. However, purchasing this recommended amount would require a substantial proportion of household income, making fruits and vegetables unaffordable in many low-income and middle-income countries. Policies that enhance the affordability of fruits and vegetables are crucially needed to meet these recommendations.

for fruit and vegetable consumption in 18 countries with different income levels. We also aimed to relate the affordability of fruits and vegetables to their consumption.

Methods

Study design and sample selection

Between Jan 1, 2003, and Dec 31, 2013, the Prospective Urban Rural Epidemiology (PURE) study enrolled 157 254 adults aged 35–70 years in 667 communities from 18 countries on five continents. Countries were selected from four income strata according to the World Bank classification in 2006 on the basis of gross national income per person. There were four LICs (Bangladesh, India, Pakistan, and Zimbabwe), four lower-middle-income countries (LMICs; China, Colombia, Iran, Occupied Palestinian Territory), seven upper-middle-income countries (UMICs; Argentina, Brazil, Chile, Malaysia, Poland, Turkey, South Africa), and three high-income countries (HICs; Canada, Sweden, United Arab Emirates). A detailed description of participant, community, and country selection has been published elsewhere (appendix pp 4–5).[13,14] In the PURE study, 147 938 participants completed country-specific, validated semi-quantitative food frequency questionnaires (appendix p 6).[15–22] Of these individuals, we included those who had plausible energy intake (500–5000 kcal per day) in our analyses of fruit and vegetable consumption.

For analyses of food availability and affordability, we collected information on the cost of at least one fruit and one vegetable in each PURE community between Jan 1, 2009, and Dec 31, 2013. A 1 km observation walk was done by research staff in a centrally located area within each community. Within each area, non-sale prices (ie, retail prices before any discounts) were collected from the grocery store or market place located in closest proximity to the observation walk zone for the following fruits and vegetables: apples, oranges, bananas, pears, carrots, tomatoes, and cabbage. A checklist of 48 types of fruits and 59 types of vegetable was used to assess the variety of fruits and vegetables available. Additional grocery stores or market places in the 1 km area were visited if research staff were unable to collect the cost of the fruits and vegetables. The total number of types of fruit and vegetable available for sale in each community was calculated to assess the diversity (see appendix p 7 for methods used to estimate fruit and vegetable availability and affordability). Additionally, we collected household income data from participants in these communities (appendix p 8). The methods used to calculate daily income, and fruit and vegetable costs and consumption are shown in appendix p 12. The study variables and their unit of analysis are summarised in appendix pp 13–14.

Statistical analysis

The affordability of two servings of fruits and three servings of vegetables per day was assessed using the least expensive fruit and vegetable available for sale within each community. Additionally, the affordability of purchasing five servings of the cheapest fruit or vegetable was assessed to estimate the most optimistic scenario of affordability that is reflective of substituting either type of produce to reach five daily servings. To define affordability, we used a threshold of less than 20% of household income per household member required to purchase two servings of fruits and three servings of vegetables per day for every household member. We used this demarcation point for affordability because we found that few households in HICs used more than 20% of

their income in the purchase of the recommended number of servings. Furthermore, when other various thresholds were explored, we found the same pattern of unaffordability across economic regions (appendix p 23). We also calculated the proportional increase in food expenditure necessary to meet the recommended intake of fruits and vegetables among individuals who did not meet this target.

We used Spearman correlation coefficients to test the strength of the association between country gross national income and mean percentage of household income spent on food. At the community level, we did an analysis of variance, with tests for linear trend, to compare the mean number of different types of fruit and vegetables (ie, diversity) and the mean cost, adjusted by purchasing price parity, of one serving of fruit and vegetables in each economic region. At the individual level, we used linear random effects models with fixed intercepts and random slope, accounting for clustering of households within communities, to examine the mean cost of one serving of fruit and one serving of vegetables in each economic region, with tests for linear trend. Additionally, linear random effects models were used to assess the mean proportion of income per household member required to purchase two servings of fruits and three servings of vegetables in each economic region. We tested for interactions between the association of availability, affordability, and income level, by urban or rural location. We did not account for clustering of individuals within households, since the mean number of participant per household was 1·4 (SD 0·6), so the degree of clustering of individuals within households would be minimal. Finally, linear random effect models with tests for linear trend were used to examine the mean intake of fruit and vegetables by their relative cost (in quartiles), adjusting for energy intake and, in a separate model, further adjusting for age as a continuous variable, and sex and economic region as categorical variables. The association between intake and relative cost was further assessed in subgroup analyses by economic region, with testing for heterogeneity in the overall sample. We used SPSS software (Armonk, NY, USA), version 22.0, for all statistical analyses.

Role of the funding source

The funder of the study had no role in the study design, data collection, data analysis, data interpretation, or writing of the report. All authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Of 147 938 PURE study participants who completed the food frequency questionnaires, 143 305 (97%) had plausible energy intake and were included in our analyses of fruit and vegetable intake (table 1). These participants and the participants who were included in community assessments generally had similar characteristics (see appendix pp 16–19 for a summary of total household size

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See **Online** for appendix

	Entire cohort (n=143 305)	High-income countries (n=15 193)	Upper-middle-income countries (n=36 875)	Lower-middle-income countries (n=59 392)	Low-income countries (n=31 845)
Median age, years (IQR)	50·0 (34·0–66·0)	53·0 (38·0–68·0)	51·0 (35·0–67·0)	51·0 (35·0–67·0)	47·0 (31·0–63·0)
Female sex	83 007 (58%)	8313 (55%)	22 251 (60%)	34 445 (58%)	17 998 (57%)
Education level					
Less than high school graduate	61 122 (43%)	1710 (11%)	19 417 (53%)	23 741 (40%)	16 254 (51%)
High school graduate	54 453 (38%)	4467 (29%)	11 816 (32%)	26 978 (45%)	11 192 (35%)
At least some college education	27 363 (19%)	9004 (59%)	5556 (15%)	8540 (14%)	4263 (13%)
Current smoker	29 852 (21%)	2083 (14%)	8297 (23%)	12 252 (21%)	7220 (23%)
High physical activity*	58 988/129 258 (46%)	7403/13 913 (53%)	14 938/31 491 (47%)	24 280/56 222 (43%)	12 367/27 632 (45%)
Mean body-mass index, kg/m² (SD)	25·8 (5·2)	27·6 (5·3)	28·4 (5·9)	25·2 (4·1)	23·3 (4·9)
Median energy intake per day, kcal (IQR)	1991 (964–3020)	2144 (1036–3252)	2057 (936–3178)	1936 (1012–2860)	1969 (891–3047)
Mean vegetable intake, servings per day (95% CI)†	2·19 (2·13–2·25)	3·58 (3·44–3·71)	1·77 (1·65–1·89)	1·96 (1·87–2·05)	1·48 (1·37–1·59)
Mean fruit intake, servings per day (95% CI)†	1·62 (1·53–1·72)	1·99 (1·79–2·19)	2·50 (2·32–2·67)	1·21 (1·06–1·35)	0·80 (0·60–1·01)
Consume ≥1 serving of vegetables per day	114 657 (80%)	14 304 (94%)	28 322 (77%)	50 761 (85%)	21 270 (67%)
Consume ≥1 serving of fruits per day	69 207 (48%)	12 364 (81%)	25 532 (69%)	22 690 (38%)	8621 (27%)

Data are n (%) or n/N (%), unless indicated otherwise. The sample comprised individuals who completed a food frequency questionnaire in the Prospective Urban Rural Epidemiology study and had an energy intake of 500–5000 kcal per day. *Defined as ≥3000 metabolic equivalent of task minutes per week; participants with missing data were excluded from analysis. †Accounting for clustering of households within communities.

Table 1: **Participant characteristics**

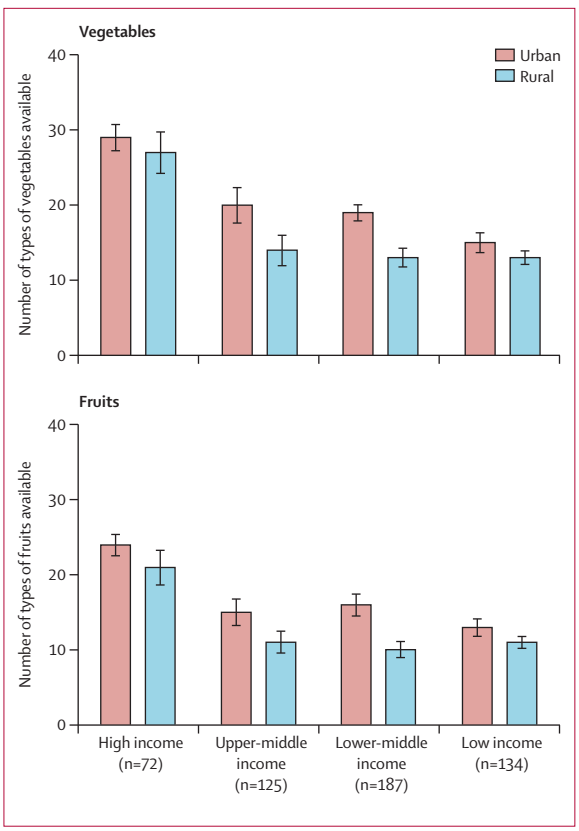

Figure 1: **Mean number of types of vegetables and fruits available in urban and rural communities, by economic region**
Error bars represent 95% CI.

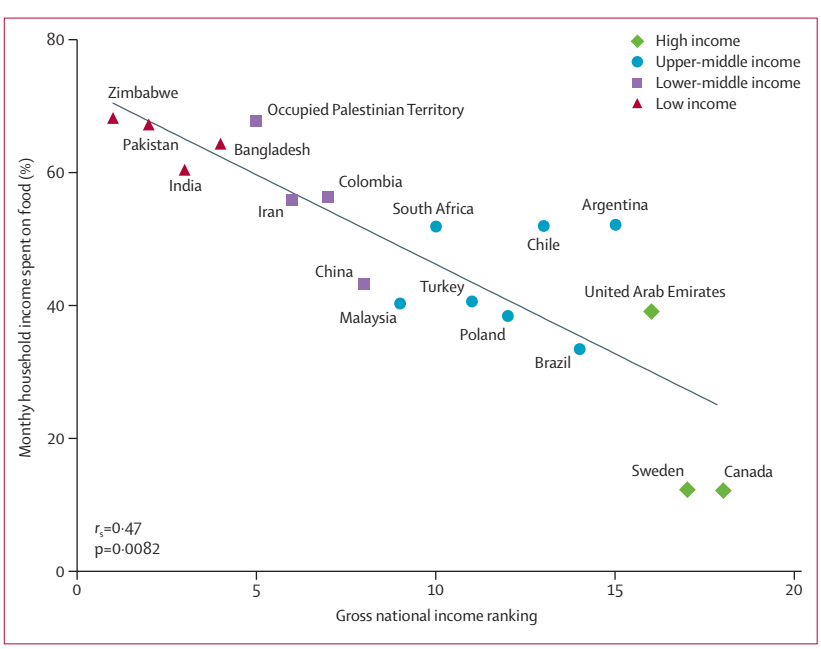

Figure 2: **Mean percentage of monthly household income spent on food, by gross national income ranking**

and composition, including household members not participating in the PURE study, by country and economic region). The median age of these 143 305 participants was 50·0 years (IQR 34·0–66·0), and men and women were equally represented. The mean body-mass index was 25·8 kg/m² (SD 5·2), 29 852 (21%) of participants were current smokers, and more than half (55%) had low or moderate physical activity levels (<600 or 600–3000 metabolic equivalent of task minutes per week, respectively). Median energy intake was 1991 kcal per day (IQR 964–3020).

Across participants in all countries studied, mean fruit and vegetable intake was 3·76 servings (95% CI 3·66–3·86) per day. Mean daily consumption of fruits and vegetables was 2·14 servings (1·93–2·36) in LICs, 3·17 servings (2·99–3·35) in LMICs, 4·31 servings (4·09–4·53) in UMICs, and 5·42 servings (5·13–5·71) in HICs. Per-person gross national income was positively associated with fruit and vegetable intake (p_{trend}=0·0020; r_s=0·37).

Data for the availability and cost of at least one fruit and one vegetable were obtained from 518 PURE communities (134 in LICs, 187 in LMICs, 125 in UMICs, and 72 in HICs). The number of different types of vegetables and fruits available for sale was greatest in HICs, intermediate in UMICs, lower in LMICs, and lowest in LICs (p_{trend}=0·00021 for vegetables, p_{trend}=0·00064 for fruits; figure 1).

We obtained household income data from 90 247 households in these communities, comprising 130 402 participants—29 421 in LICs, 52 090 in LMICs, 35 069 in UMICs, and 13 822 in HICs. A strong, inverse association exists between gross national income ranking and mean proportion of total household income spent on food (figure 2). Worldwide, the mean proportion of household income spent on food was 42·40% (95% CI 41·24–43·56). Households in HICs spend the smallest proportion (13·30%, 10·27–16·24) of their income purchasing food, compared with 42·15% (39·91–44·39) in UMICs, 52·30% (50·48–54·11) in LMICs, and 61·84% (59·69–64·00) in LICs.

At the community level, the absolute cost (adjusted by purchasing price parity) of one serving of vegetables was cheapest in LICs and most expensive in HICs (p_{trend}=0·0023; table 2). Conversely, the adjusted cost of one serving of fruit was highest in LICs (p_{trend}=0·0061; table 2). The cost of one serving of vegetables relative to income per household member was more than 19 times higher in LICs than in HICs (p_{trend}=0·00029), and the relative cost of one serving of fruit was 50 times higher in LICs than in HICs (p_{trend}=0·00011; table 2). The relative cost of fruit was more expensive than that of vegetables in each region (table 2). Mean daily income per household member was greatest in HICs and lowest in LICS, and greater in urban communities than rural communities across all income regions (table 2).

	High-income countries	Upper-middle-income countries	Lower-middle-income countries	Low-income countries	p_{trend}
Mean (95% CI) absolute cost of one portion (international dollars)					
Vegetables	$0·24 (0·22 to 0·25)	$0·19 (0·18 to 0·20)	$0·13 (0·12 to 0·14)	$0·11 (0·10 to 0·11)	0·0023
Fruits	$0·25 (0·24 to 0·27)	$0·26 (0·25 to 0·28)	$0·22 (0·21 to 0·23)	$0·33 (0·32 to 0·35)	0·0061
Mean (95% CI) proportion of household income spent*					
Vegetables	0·54% (–1·02 to 2·10)	3·97% (2·49 to 5·45)	3·90% (2·94 to 4·86)	10·54% (8·95 to 12·13)	0·00029
Fruits	0·59% (–2·11 to 3·29)	5·19% (3·14 to 7·24)	6·20% (4·53 to 7·87)	29·37% (26·61 to 32·13)	0·00011
Mean (95% CI) daily income per household member (international dollars)					
Urban	$68·36 (67·74 to 68·67)	$26·74 (18·81 to 19·50)	$9·60 (9·33 to 9·88)	$7·18 (6·62 to 7·73)	..
Rural	$56·27 (55·83 to 56·72)	$9·15 (8·92 to 9·38)	$5·36 (5·18 to 5·55)	$1·92 (1·57 to 2·27)	..

*Cost relative to income per household member.

Table 2: **Absolute cost, adjusted by purchasing price parity, and proportion of household income spent on one serving of vegetables and fruits, and daily income per household member, by economic region**

Overall, 21·95% (95% CI 19–45–24·45) of income per household member was needed to purchase two servings of fruits and three servings of vegetables. Participants in LICs spend the largest proportion of their income to meet the recommendation (51·97%, 46·06–57·88), compared with 18·10% (14·53–21·68) in LMICs, 15·87% (11·51–20·23) in UMICs, and 1·85% (–3·90 to 7·59) in HICs (p_{trend}=0·0001; figure 3A). In all regions, a higher proportion of income to meet the recommended intake was required in rural areas than in urban areas (p<0·0001 for all pairwise comparisons), particularly in UMICs, LMICs, and LICs ($p_{heterogeneity}$=0·0048).

The proportion of individuals who could not afford the recommended daily intake was highest in LICs (57·42%, 95% CI 56·58–58·26), compared with 25·42% (24·95–25·89) in UMICs, 17·68% (17·35–18·01) in LMICs, and 0·25% (0·17–0·33) in HICs (p_{trend}=0·0082; figure 3B). In all regions, unaffordability was higher in rural areas than in urban areas (p=0·027 for all urban *vs* rural pairwise comparisons).

86 506 (60%) participants did not meet the recommended fruit and vegetable intake, and a shift in diet to meet this recommendation would increase food expenditure by 0·45% (95% CI –2·68 to 3·58) of household income in HICs, 7·71% (5·31–10·1) in UMICs, 10·3% (8·14–12·4) in LMICs, and 25·4% (22·0–28·7) in LICs. The increase would be significantly steeper in rural areas than in urban areas ($p_{heterogeneity}$=0·00024; appendix p 25).

Both vegetable and fruit consumption decreased as the relative cost per serving increased, after adjusting for energy intake, age, sex, and economic region (p_{trend}=0·00071 for vegetables and p_{trend}=0·00033 for fruit for vegetables and for fruits; figure 4). Combined fruit and vegetable intake decreased as the relative cost of two servings of fruits and three servings of vegetables per day increased, both overall (p_{trend}=0·00040) and by economic region, except in HICs (figure 5).

When we recalculated income per household member using a weighted approach (reflecting the lower energy needs of children), the association between the relative cost of one serving of vegetables and fruit with economic region persisted (appendix p 22). When examining the association between the affordability of current vegetable and fruit recommendations and economic region, the results were again similar (appendix p 22).

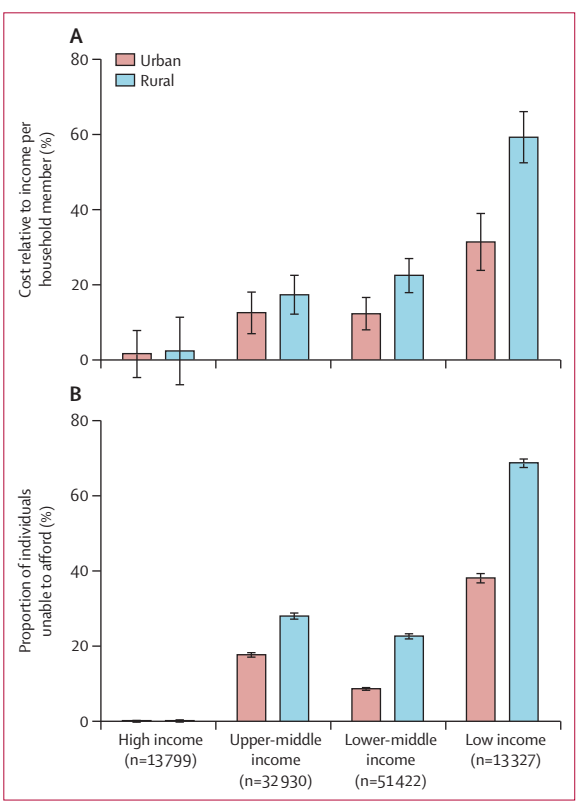

Figure 3: **(A) Mean proportion of income per household member required to purchase three servings of vegetables and two servings of fruits per day and (B) proportion of individuals who were unable to afford three servings of vegetables and two servings of fruits per day**

Error bars represent 95% CI.

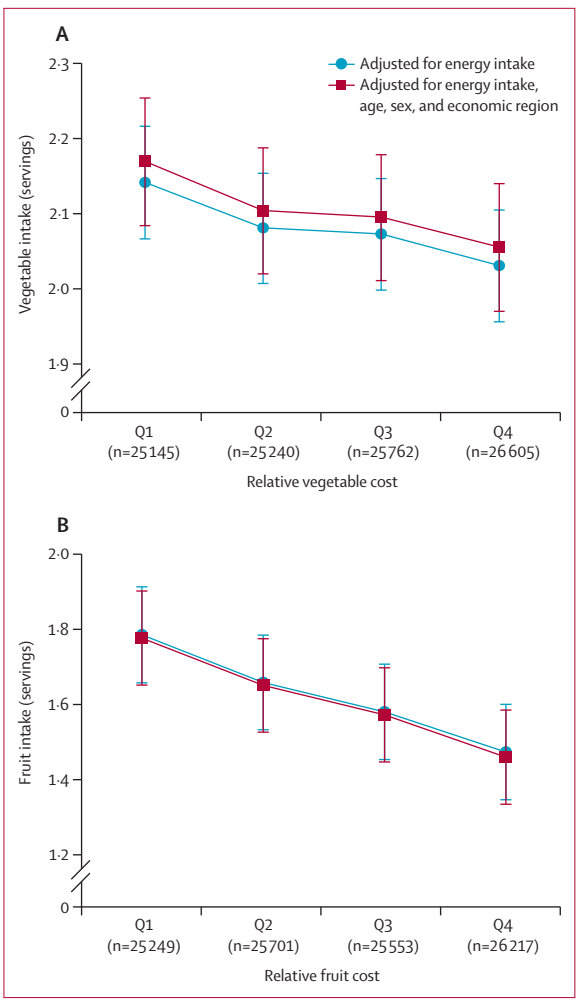

Figure 4: **Mean intake of (A) vegetables and (B) fruits per person adjusted for covariates, by relative cost**
Error bars represent 95% CI. Q=quartile.

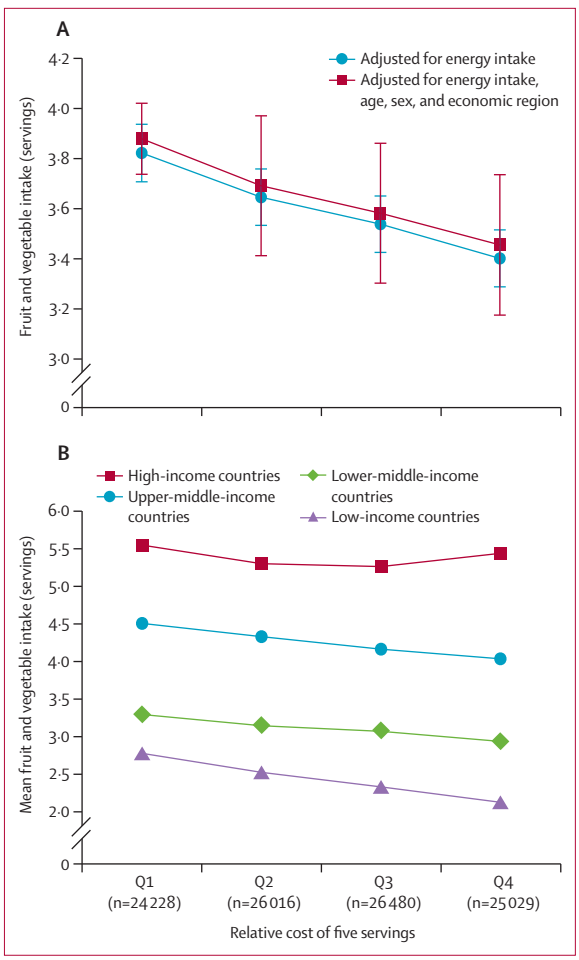

Figure 5: **Mean vegetable and fruit intake per person by relative cost of three servings of vegetables and two servings of fruits (A) in the overall sample, adjusting for covariates, and (B) stratified by economic region, adjusting for energy intake, age, and sex**
Error bars represent 95% CI. Q=quartile.

Discussion

In this study of 18 countries with a range of income levels, we found that individuals in countries with low gross national income consume fewer fruits and vegetables and spend a greater proportion of their income purchasing food than those in high-income countries. Absolute fruit cost was highest in communities of LICs, whereas vegetable cost was lowest in these communities adjusted by purchasing price parity). However, the costs of both fruits and vegetables (relative to household income) were substantially higher for individuals in countries with low gross national income than in other economic regions. Furthermore, in LICs, households spend 29% and 11% of their income to purchase one serving of fruits and vegetables, respectively, and the dietary recommendation of two servings of fruits and three servings of vegetables per day was unaffordable for 57% of individuals. Unsurprisingly, increased costs of fruits and vegetables relative to household income were associated with reduced consumption.

Households in LICs and LMICs spend a substantial proportion (roughly half) of their income on food (compared with 13% in HICs), with households in some countries (eg, Occupied Palestinian Territory, Bangladesh, Pakistan, and Zimbabwe) spending about two-thirds of their income on food (figure 2). These findings are consistent with previous work showing that food spending ranges from 35% to 65% in MICs[23] and from 55% to 77% in LICs.[23,24] However, our findings of the relative costs of fruits and vegetables could not be compared with previous work in LICs or MICs because few such countries systematically monitor the cost of food and disclose national statistics.[25] Moreover, the national estimates of the cost of major food commodities available from the World Bank[26] and the UN Food and Agriculture Organization[27] do not include fruits and vegetables.

The consumption of a variety of fruits and vegetables is important to a high-quality diet.[28,29] In the PURE study, most participants consumed fewer than the recommended five daily servings of fruits and vegetables, and mean vegetable intake was lower than the recommended three daily servings in all economics regions except HICs (table 1). In 2015, global fruit and vegetable intake was estimated to be lower than the average observed in our study.[30] Of note, previous estimates were mainly based on qualitative questionnaires, shorter dietary tools, or household surveys. These dietary tools are brief questionnaires in which a structured list of food items is absent and as few as one question might be used to estimate the consumption of a particular food type. This method does not include portion sizes to quantify level of intake and provides a less precise estimate of absolute intake than 24 h dietary recall or semi-quantitative food frequency questionnaires.[31] The household surveys are useful for monitoring food commodity use, but they might not be appropriate for measuring absolute dietary intake or energy intake because they reflect both intake and food lost through waste at the retail, food service, and household level.[32] Among studies of HICs using semi-quantitative food frequency questionnaires and with similar age and sex characteristics as the PURE study, our estimates of mean fruit and vegetable intake correspond closely with those in other similar populations (appendix p 11).[33,34]

Our study has a few limitations. First, fruit and vegetable costs were not recorded in 80 communities (11953 participants), most of which were in LMICs. Since fruit and vegetable costs might vary across communities, imputing costs was unlikely to reflect the heterogeneity in prices. Our sample included a small representation of participants in South Africa and Zimbabwe because of missing data for fruit and vegetable costs and household income. However, the participants of the PURE study and non-participants included in our analysis were similar in baseline characteristics, so potential biases resulting from exclusion of participants were likely to be minimal. Second, a true probability sampling approach was not used to select our study population. Such a method was not feasible because of the many practical constraints of studying food cost and availability in a wide range of countries and settings. The fact that sampling was not random should be considered when interpreting the generalisability of our findings but should not compromise the internal validity. Third, the costs of the different fruits and vegetables were collected at the community level and assumed to reflect the average cost that households would pay. The costs were collected from grocery stores located centrally in each community to ensure that the costs were representative of most households. Fourth, we did not account for seasonal differences in prices, since we did not collect the cost of fruits and vegetables in each community at different times of the year. However, these data were collected over several seasons for most countries (appendix p 15). Because many of the countries have fairly uniform climate (particularly in LICs and MICs), the results are likely to provide a reasonable approximation of the average seasonal price for fruit and vegetable items in these communities.

Fifth, costs were collected for fruits and vegetables that were thought to be the most widely available in most countries, but not necessarily the cheapest or most regularly consumed items within all countries. The fruits and vegetables chosen were widely available across economic regions, with the exception of pears and cabbage in LICs (appendix p 20). Furthermore, the least expensive fruit and vegetable items in each economic region were available for sale in most communities (appendix p 21). The interpretation of the affordability of fruits and vegetables might be limited to these commonly available produce, and cheaper alternatives might have been accessible. Nevertheless, fruit and vegetable intake was assessed using country-specific food frequency questionnaires that reflected the individual food items most commonly consumed in each country, and we still found a strong graded association with fruit and vegetable cost. Additionally, the cost of fruits and vegetables were collected as non-sale prices, since sale prices might change on a daily or weekly basis, thus increasing the variability of estimates, whereas the non-sale prices would be expected to provide a more consistent estimate of costs within and across communities. Finally, the data presented are cross-sectional, and inferences cannot be made about the causal relation between affordability and consumption of fruits and vegetables.

This study provides an international comparison of fruit and vegetable costs and affordability using a standardised and validated instrument. Another important strength of this study is the large sample size and heterogeneity of the study population. Additionally, a large proportion of study participants are from MICs and LICs, for which limited information on food affordability is available.

Hunger and under-nutrition remain highly prevalent in many LICs and MICs,[35] and nutrition strategies in these countries often prioritise meeting the minimum energy intake over diet quality. The unaffordability of fruits and vegetables might be a large barrier to achieving these nutritional targets. Worldwide, 1·7 million annual deaths are estimated to be associated with low fruit and vegetable intake,[36] and many populations are unable to meet the dietary recommendations. Our results show that increased cost of fruits and vegetables relative to household income was associated with reduced consumption, highlighting the need for policies that expand affordability and availability of these foods, which might improve the diet quality of many populations, especially in LICs and LMICs.

Contributors
VM and AM designed the study, were involved in data management and statistical analysis, and wrote the first and subsequent drafts of the report. SY designed the study, conceived and initiated the Prospective Urban Rural Epidemiology (PURE) study, supervised its conduct and data analysis, and provided crucial comments on all drafts of the report. CKC, DJC, and KL conceived and initiated the Environmental Profile of a Community's Health (EPOCH) study, supervised its conduct, and provided crucial comments on all drafts of the report. MD developed and validated the country-specific food frequency questionnaires, supervised the collection of dietary information, and commented on drafts of the report. SR coordinated the worldwide PURE study and reviewed and commented on drafts of the report. KT was the coprincipal investigator of the PURE study and reviewed and commented on drafts of the report. All other authors coordinated the study, collected data in their respective countries, and provided comments on drafts of the report.

Declaration of interests
We declare no competing interests.

Acknowledgments
The main PURE study and its components are funded by the Population Health Research Institute; the Canadian Institutes of Health Research; the Heart and Stroke Foundation of Ontario (Canada); unrestricted grants from AstraZeneca (Sweden, Canada, Turkey), Sanofi-Aventis (France, Canada, Turkey), Boehringer Ingelheim (Germany and Canada), Servier, GlaxoSmithKline, Novartis, King Pharma; the Bangladesh Independent University; Mitra and Associates (Bangladesh); Unilever Health Institute (Brazil); Public Health Agency of Canada; Champlain Cardiovascular Disease Prevention Network (Canada); Universidad de la Frontera (Chile); National Center for Cardiovascular Diseases (China); Colciencias (Colombia; grant number 6566-04-18062); Indian Council of Medical Research; Malaysian Ministry of Science, Technology and Innovation (grant number 07-05-IFN-MEB010); Malaysian Ministry of Higher Education (grant number 600-RMI/ LRGS/5/3); Universiti Kebangsaan Malaysia (UKM-Hejim-Komuniti-15-2010); Polish Ministry of Science and Higher Education (grant number 290/W-PURE/2008/0); Wroclaw Medical University (Poland); North-West University (South Africa); South Africa Netherlands Research Programme on Alternatives in Development (SANPAD); National Research Foundation (South Africa); Medical Research Council of South Africa; the South Africa Sugar Association (SASA); Faculty of Community and Health Sciences (University of the Western Cape, South Africa); Council for Working Life and Social Research (Sweden); Swedish Research Council for Environment; Agricultural Sciences and Spatial Planning (Sweden); Swedish Heart and Lung Foundation; Swedish Research Council; grant from the Swedish State under LUA (LäkarUtbildningsAvtalet) agreement; grant from the Västra Götaland Region (FOUU; Sweden); Metabolic Syndrome Society; and the Sheikh Hamdan Bin Rashid Al Maktoum Award For Medical Sciences (Dubai Health Authority). AM is a recipient of a Research Early Career Award from Hamilton Health Sciences Foundation. SY is funded by the Marion Burke Chair of the Heart and Stroke Foundation of Canada and is President of the World Heart Federation. This paper does not necessarily reflect the position of the World Heart Federation or any other organisation.

References

1 Joint WHO/FAO expert consultation on diet, nutrition and the prevention of chronic diseases. Geneva: Joint FAO/WHO Expert Consultation, 2003.
2 The world health report 2002—reducing risks, promoting healthy life. Geneva: World Health Organization, 2003.
3 Hall JN, Moore S, Harper SB, Lynch JW. Global variability in fruit and vegetable consumption. *Am J Prev Med* 2009; **36:** 402–09.
4 Murphy MM, Barraj LM, Spungen JH, Herman DR, Randolph RK. Global assessment of select phytonutrient intakes by level of fruit and vegetable consumption. *Br J Nutr* 2014; **112:** 1004–08.
5 Del Gobbo LC, Khatibzadeh S, Imamura F, et al. Assessing global dietary habits: a comparison of national estimates from the FAO and the Global Dietary Database. *Am J Clin Nutr* 2015; **101:** 1038–46.
6 Power EM. Determinants of healthy eating among low-income Canadians. *Can J Public Health* 2005; **96** (suppl 3): S37–42, S42–48.
7 Steenhuis IH, Waterlander WE, de Mul A. Consumer food choices: the role of price and pricing strategies. *Public Health Nutr* 2011; **14:** 2220–26.
8 Brinkman HJ, de Pee S, Sanogo I, Subran L, Bloem MW. High food prices and the global financial crisis have reduced access to nutritious food and worsened nutritional status and health. *J Nutr* 2010; **140:** 153S–61S.
9 Gustafson DJ. Rising food costs & global food security: key issues & relevance for India. *Indian J Med Res* 2013; **138:** 398–410.
10 Ruel MT, Garrett JL, Hawkes C, Cohen MJ. The food, fuel, and financial crises affect the urban and rural poor disproportionately: a review of the evidence. *J Nutr* 2010; **140:** 170S–6S.
11 Klotz C, de Pee S, Thorne-Lyman A, Kraemer K, Bloem M. Nutrition in the perfect storm: why micronutrient malnutrition will be a widespread health consequence of high food prices. *Sight and Life Magazine* 2008; **2:** 6–11.
12 D'Souza A, Joliffe D. Conflict, food price shocks, and food security: the experience of Afghan households. IZA Discussion Paper number 6621. Institute for the Study of Labor, 2012. http://ftp.iza.org/dp6621.pdf (accessed June 30, 2016).
13 Teo K, Chow CK, Vaz M, Rangarajan S, Yusuf S, PURE Investigators-Writing Group. The Prospective Urban Rural Epidemiology (PURE) study: examining the impact of societal influences on chronic noncommunicable diseases in low-, middle-, and high-income countries. *Am Heart J* 2009; **158:** 1–7.
14 Corsi DJ, Subramanian SV, Chow CK, et al. Prospective Urban Rural Epidemiology (PURE) study: baseline characteristics of the household sample and comparative analyses with national data in 17 countries. *Am Heart J* 2013; **166:** 636–646.e4.
15 Kelemen LE, Anand SS, Vuksan V, et al. Development and evaluation of cultural food frequency questionnaires for South Asians, Chinese, and Europeans in North America. *J Am Diet Assoc* 2003; **103:** 1178–84.
16 Bharathi AV, Kurpad AV, Thomas T, Yusuf S, Saraswathi G, Vaz M. Development of food frequency questionnaires and a nutrient database for the Prospective Urban and Rural Epidemiological (PURE) pilot study in South India: methodological issues. *Asia Pac J Clin Nutr* 2008; **17:** 178–85.
17 Dehghan M, Martinez S, Zhang X, et al. Relative validity of an FFQ to estimate daily food and nutrient intakes for Chilean adults. *Public Health Nutr* 2013; **16:** 1782–88.
18 Dehghan M, del Cerro S, Zhang X, et al. Validation of a semi-quantitative Food Frequency Questionnaire for Argentinean adults. *PLoS One* 2012; **7:** e37958.
19 Dehghan M, Ilow R, Zatonska K, et al. Development, reproducibility and validity of the food frequency questionnaire in the Poland arm of the Prospective Urban and Rural Epidemiological (PURE) study. *J Hum Nutr Diet* 2012; **25:** 225–32.
20 Dehghan M, Lopez Jaramillo P, Duenas R, et al. Development and validation of a quantitative food frequency questionnaire among rural- and urban-dwelling adults in Colombia. *J Nutr Educ Behav* 2012; **44:** 609–13.
21 Dehghan M, Al Hamad N, Yusufali A, Nusrath F, Yusuf S, Merchant AT. Development of a semi-quantitative food frequency questionnaire for use in United Arab Emirates and Kuwait based on local foods. *Nutr J* 2005; **4:** 18.
22 Merchant AT, Dehghan M, Chifamba J, Terera G, Yusuf S. Nutrient estimation from an FFQ developed for a Black Zimbabwean population. *Nutr J* 2005; **4:** 37.
23 Banerjee AV, Duflo E. What is middle class about the middle classes around the world? *J Econ Perspect* 2008; **22:** 3–28.
24 FAO, IFAD, WFP. How does international price volatility affect domestic economies and food security. Rome: Food and Agriculture Organization, 2011.
25 Lee A, Mhurchu CN, Sacks G, et al. Monitoring the price and affordability of foods and diets globally. *Obes Rev* 2013; **14** (suppl 1): 82–95.
26 World Bank. Food price watch. Washington, DC: World Bank, 2014.
27 FAO. World food situation: food price index. Rome: Food and Agriculture Organization, 2015.
28 Liu RH. Health benefits of fruit and vegetables are from additive and synergistic combinations of phytochemicals. *Am J Clin Nutr* 2003; **78:** 517S–20S.

29 Cooper AJ, Sharp SJ, Lentjues MA, et al. A prospective study of the association between quantity and variety of fruit and vegetable intake and incident type 2 diabetes. *Diabetes Care* 2012; **35:** 1293–300.

30 Micha R, Khatibzadeh S, Shi P, Andrews KG, Engell RE, Mozaffarian D. Global, regional and national consumption of major food groups in 1990 and 2010: a systematic analysis including 266 country-specific nutrition surveys worldwide. *BMJ Open* 2015; **5:** e008705.

31 Thompson FE, Subar AF. Nutrition in the prevention and treatment of disease. In: Coulston AM, Rock CL, Monsen ER, eds. Dietary assessment methodology. San Diego: Academic Press, 2001.

32 Lock K, Pomerleau J, Causer L, McKee M. Low fruit and vegetable consumption. In: Ezzati M, Lopez AD, Rodgers A, Murray CJL, eds. Comparative quantification of health risks: global and regional burden of disease attributable to selected major risk factors. Geneva: World Health Organization, 2004: 597–727.

33 Rohrmann S, Giovannucci E, Willett WC, Platz EA. Fruit and vegetable consumption, intake of micronutrients, and benign prostatic hyperplasia in US men. *Am J Clin Nutr* 2007; **85:** 523–29.

34 Corley J, Kyle JA, Starr JM, McNeill G, Deary IJ. Dietary factors and biomarkers of systemic inflammation in older people: the Lothian Birth Cohort 1936. *Br J Nutr* 2015; **114:** 1088–98.

35 FAO, IFAD, WFP. The state of food insecurity in the world 2013. Rome: Food and Agriculture Organization, 2013.

36 Lim SS, Vos T, Flaxman AD, et al. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 2012; **380:** 2224–60.